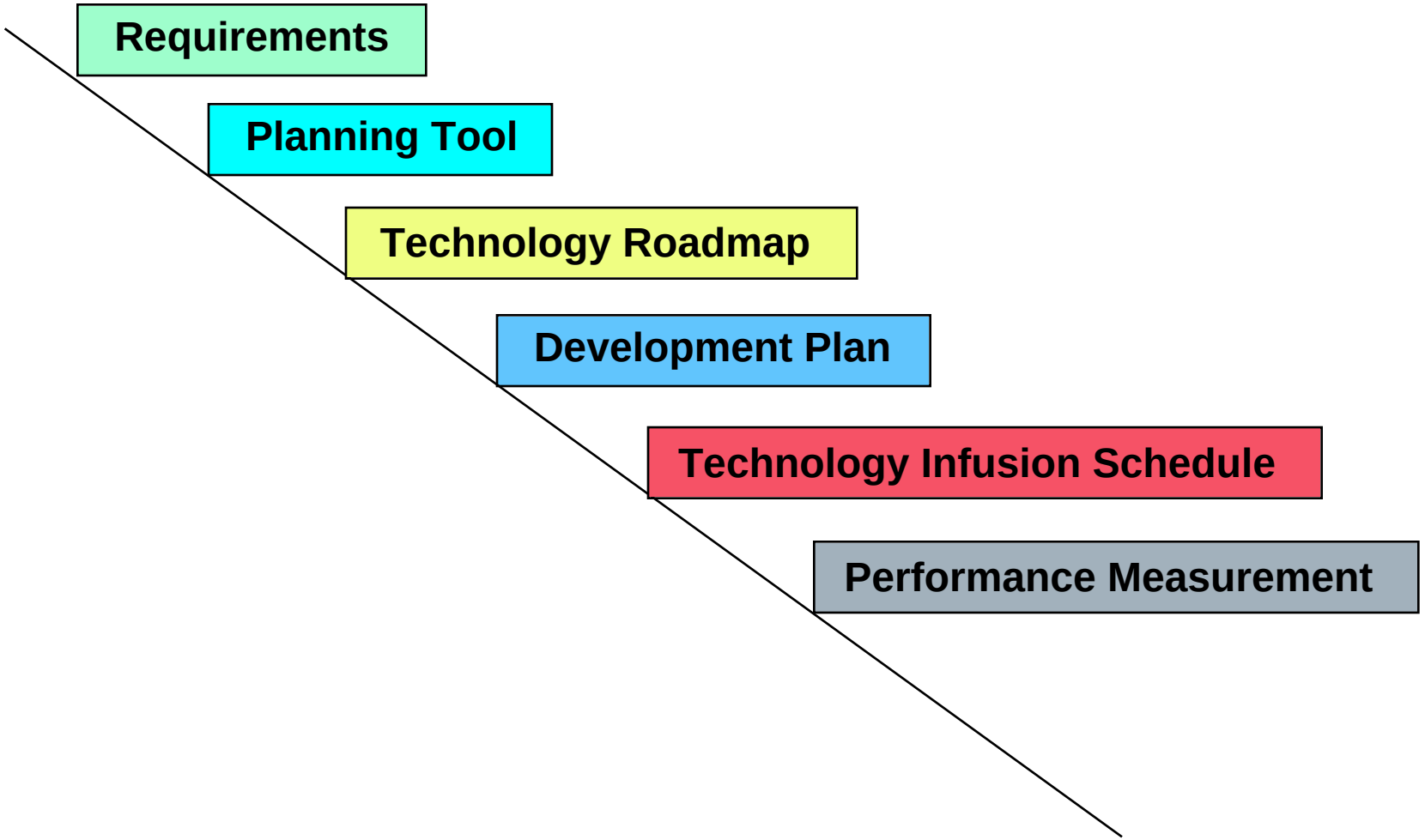
Earth Science Enterprise Technology Strategy and Implementation

George J. Komar

January 1999

ESTO Program



Scientific and Applications Measurement Set

Atmospheric Chemistry
- Stratospheric Chemistry
- Tropospheric Chemistry

Atmospheric Physics
- Aerosol Properties
- Atmospheric Humidity
- Atmospheric Temperature
- Cloud Properties
- Radiative Energy Fluxes
- Total Solar Irradiance

Geodynamics, Geology & Applications
- Earth Surface Deformation Mapping
- Gravity Field Mapping
- Magnetic Field Mapping
- Volcanic Ash Cloud Tracking

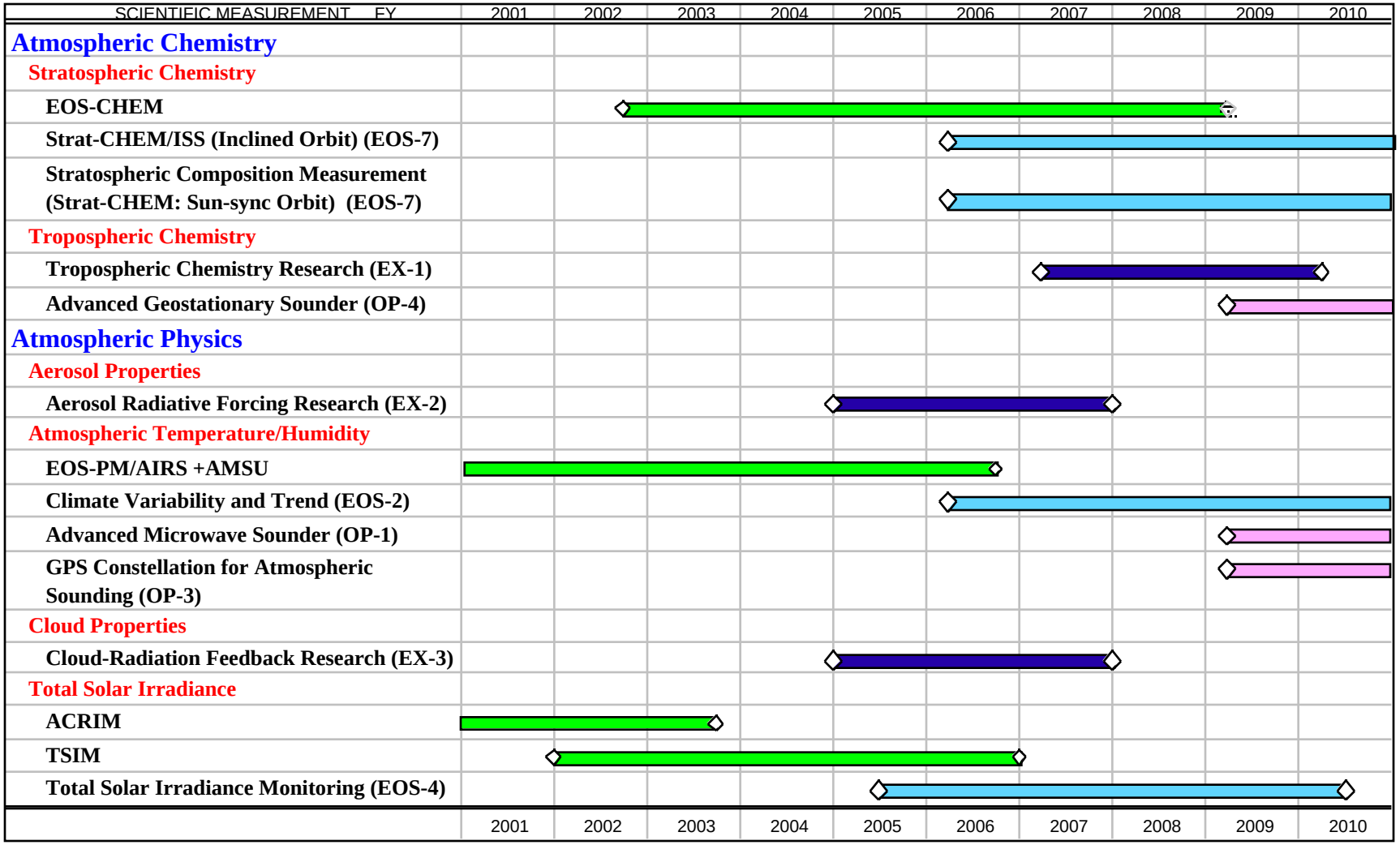
Global Water Cycle and Weather
- Cold Hydrologic Process
- Precipitation
- Soil Moisture
- Surface Flow
- Tropospheric Wind

Land Cover and Terrestrial Ecosystems
- Land Cover & Land Use Change
- Vegetation Disturbance Recovery

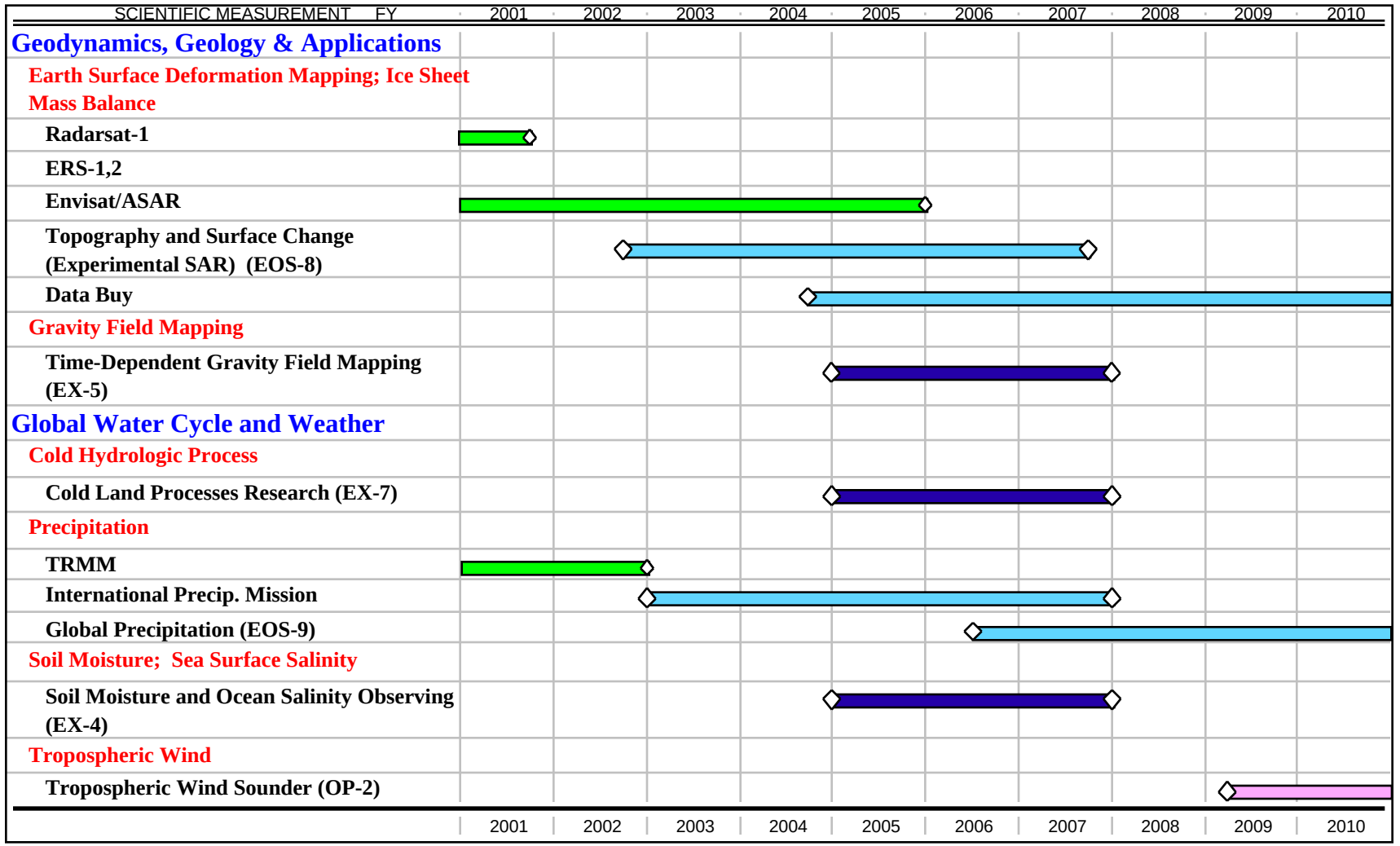
Natural Hazards
- Lightning/Volcanic Ash Cloud/Fire Occurrence

Ocean and Ice
- Ice Sheet Mass Balance
- Ocean Color Mapping
- Ocean Surface Topography
- Ocean Surface Wind
- Sea Surface Salinity

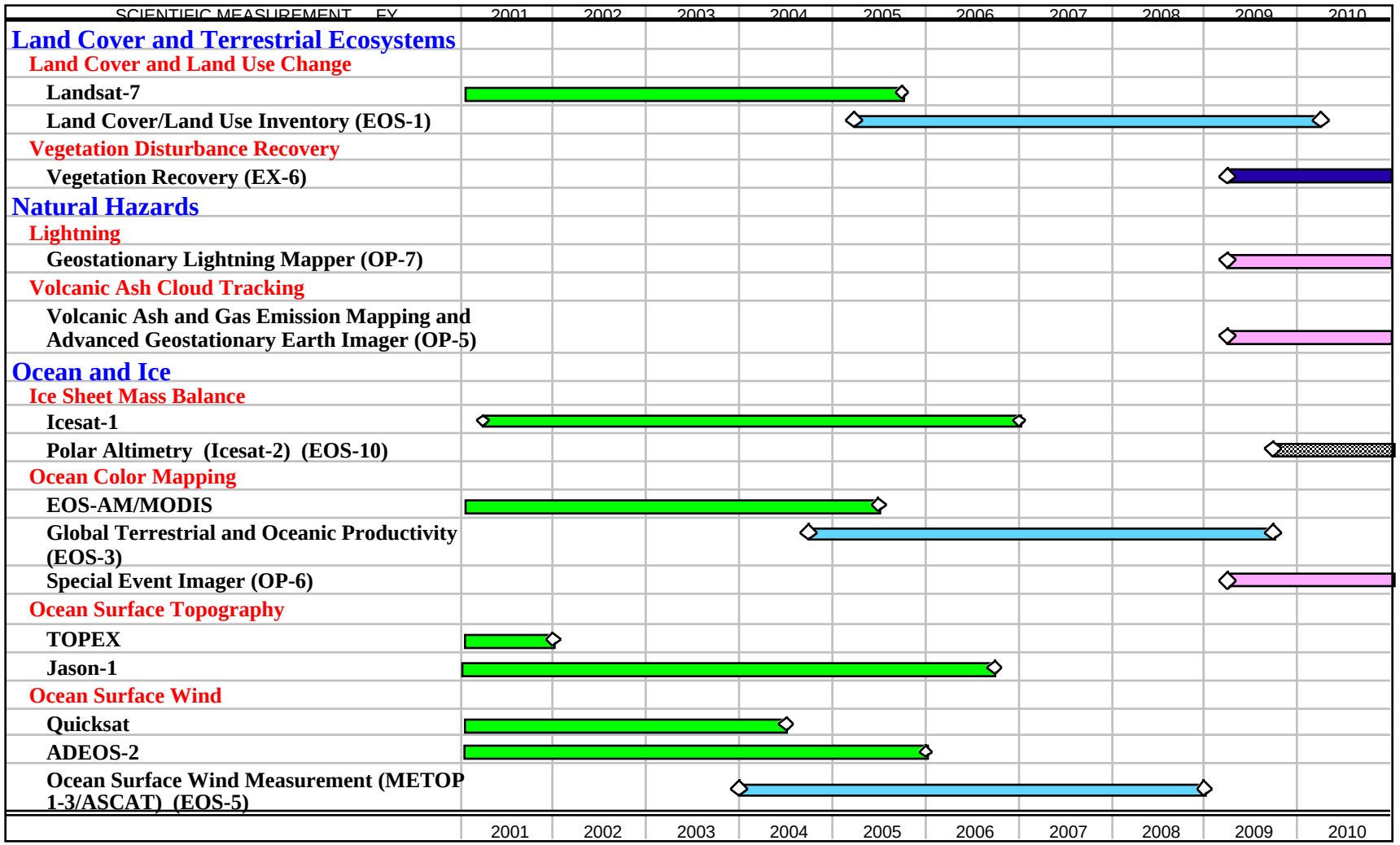
ESE Notional Measurement Scenario Post - 2002



ESE Notional Measurement Scenario Post - 2002

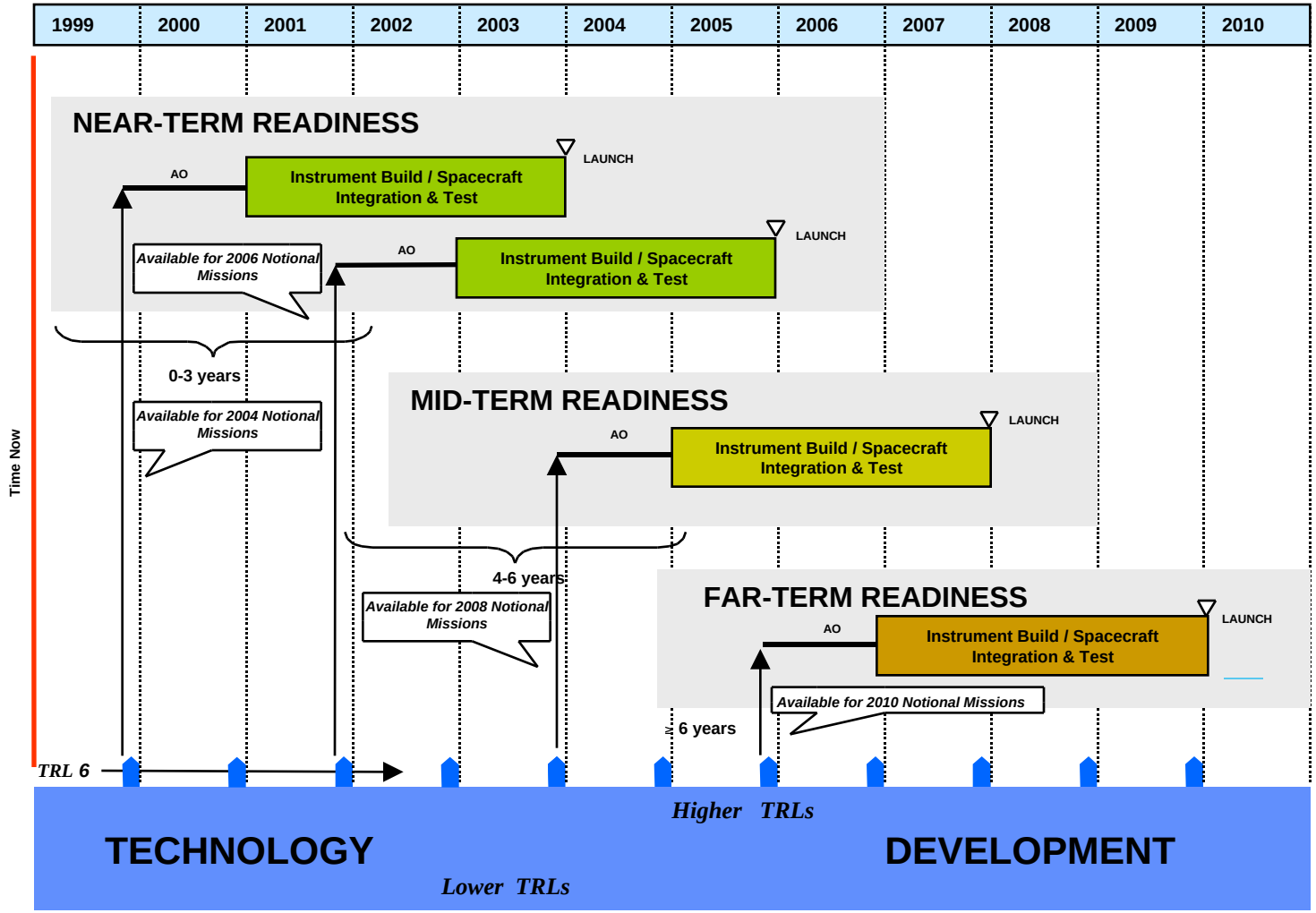


ESE Notional Measurement Scenario Post - 2002



Technology Infusion into the Notional Measurements

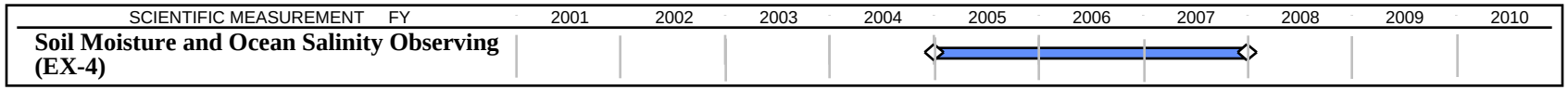
- using a biennial AO model -



Needs Matrix Content

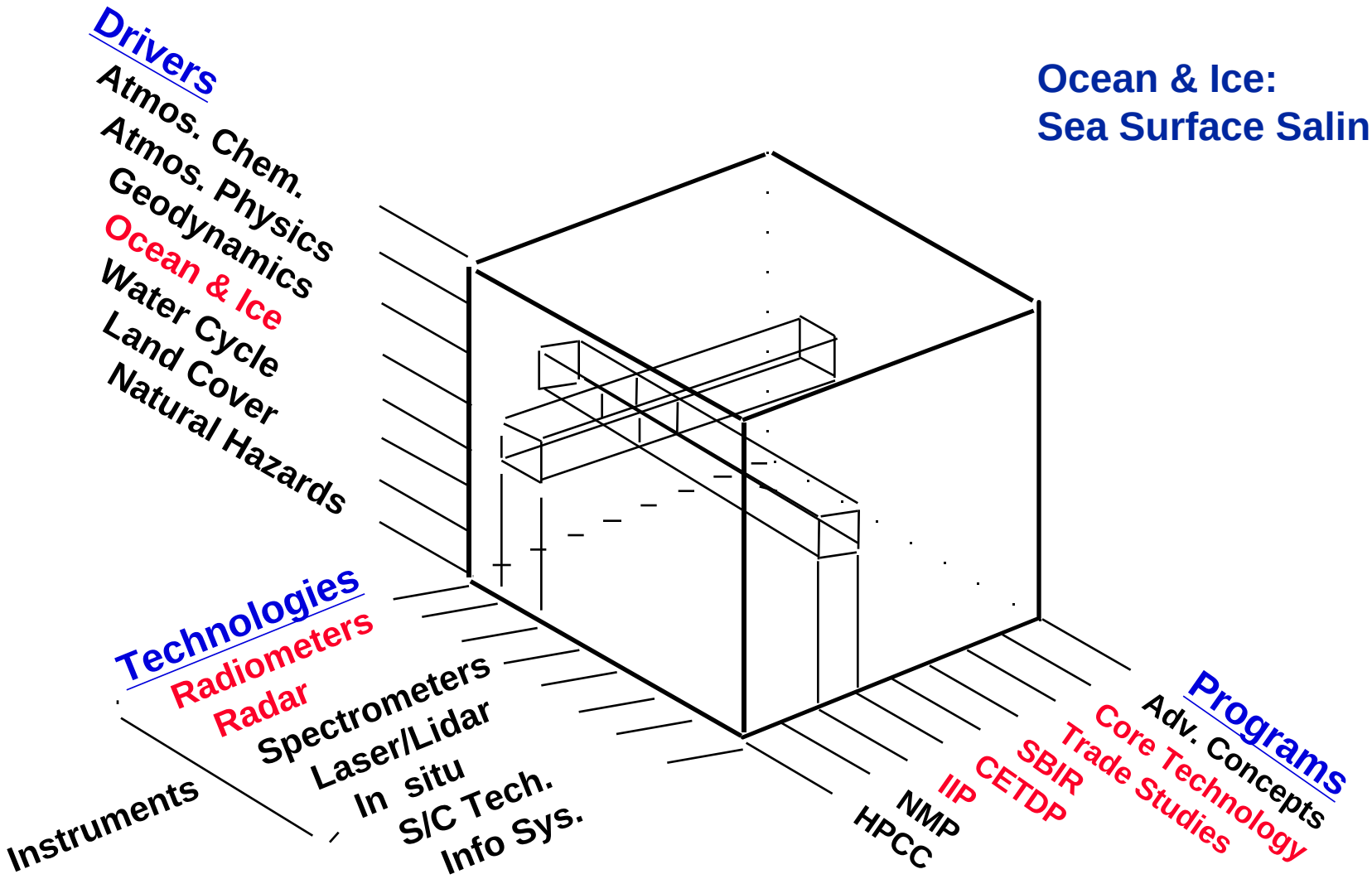
- **SCIENCE DRIVERS**
  - LAND-COVER, LAND-USE AND GLOBAL PRODUCTIVITY Sec. 2
  - SEASONAL-TO-INTERANNUAL CLIMATE VARIABILITY & PREDICTION Sec. 3
  - LONG-TERM CLIMATE: NATURAL VARIABILITY & CHANGE RESEARCH Sec. 4
  - NATURAL HAZARDS RESEARCH & APPLICATIONS Sec. 5
  - ATMOSPHERIC CHEMISTRY & OZONE RESEARCH Sec. 6
- **PROGRAMMATIC DRIVERS**
  - NOAA/IPO/NPOESS (Weather) Sec. 7
  - OTHER AGENCIES (Natural Hazards, National Defense) Sec. 7
- **ARCHITECTURAL DRIVERS (Cross Cutting Capabilities)**
  - MULTI-PLATFORM COORDINATED MEASUREMENTS Sec. 8
  - MINIATURE, LOW-COST, LOW-POWER MISSIONS Sec. 9
  - DATA-INTENSIVE MEASUREMENTS Sec. 10

Needs Matrix: Physical Oceanography

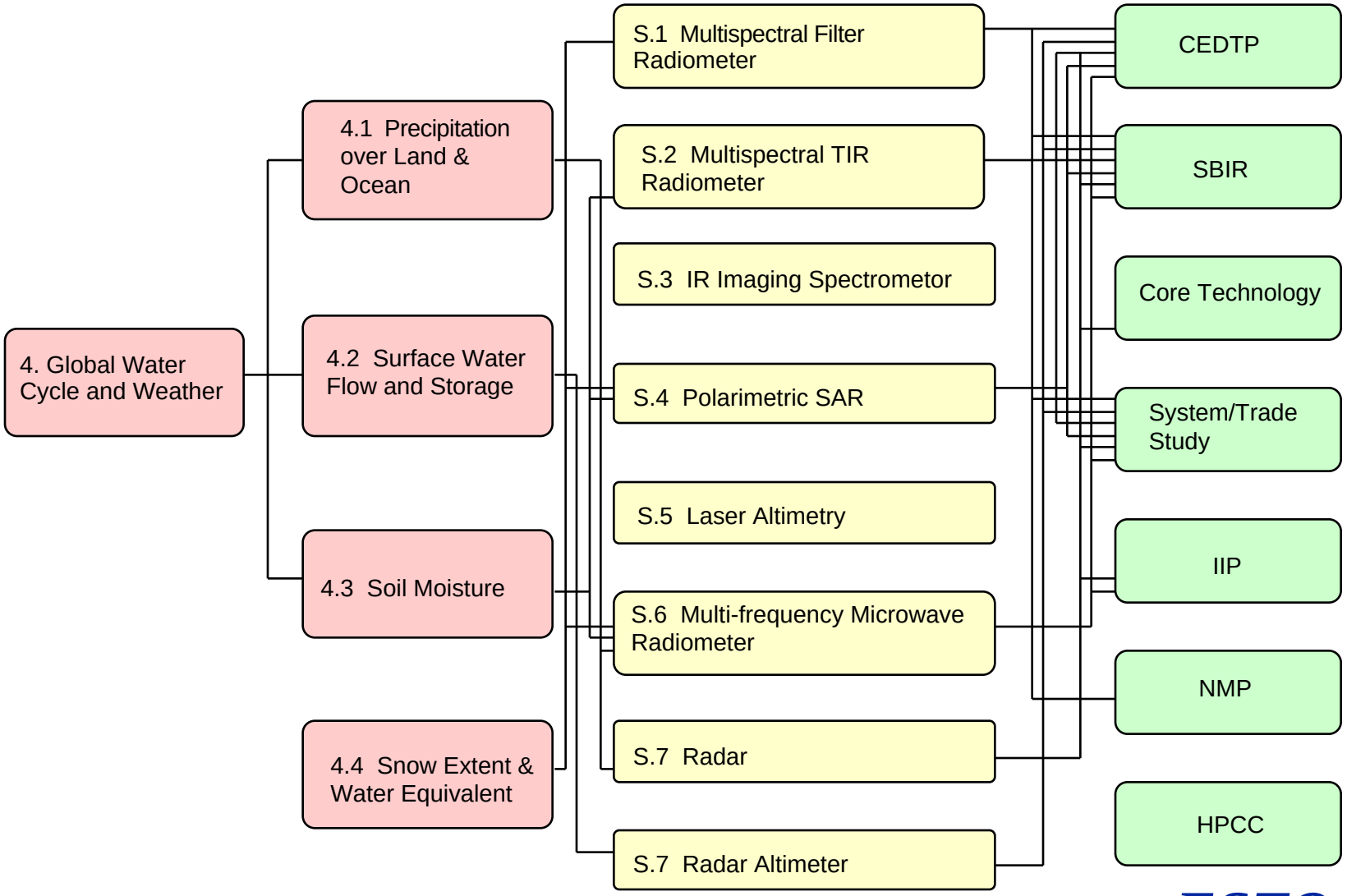


- **Sea Surface Salinity**:
  - global ocean coverage
  - horizontal res. 100 km
  - revisit time 1-2 days
  - precision ~ 1 psu (practical salinity unit) or better
- **Physical Measurement:**
  - Thermal microwave emission from the ocean surface:
  - 1/10 degree precision on temperature measurement
- **Future**: In-space multifrequency imaging radiometer:
- **Challenges**:
  - req'd spatial resolution implies minimum antenna aperture of 10 - 20 m
  - multifrequency measurements with > 1 decade difference in frequency
- **System Requirements:**
  - large, lightweight deployable antenna
  - multiple lightweight microwave radiometers (MMICs)
  - common calibration methods with required 1/10 degree precision
  - antenna surface precision to 1/100 wavelength

Science, Technology and Program Cross-Link



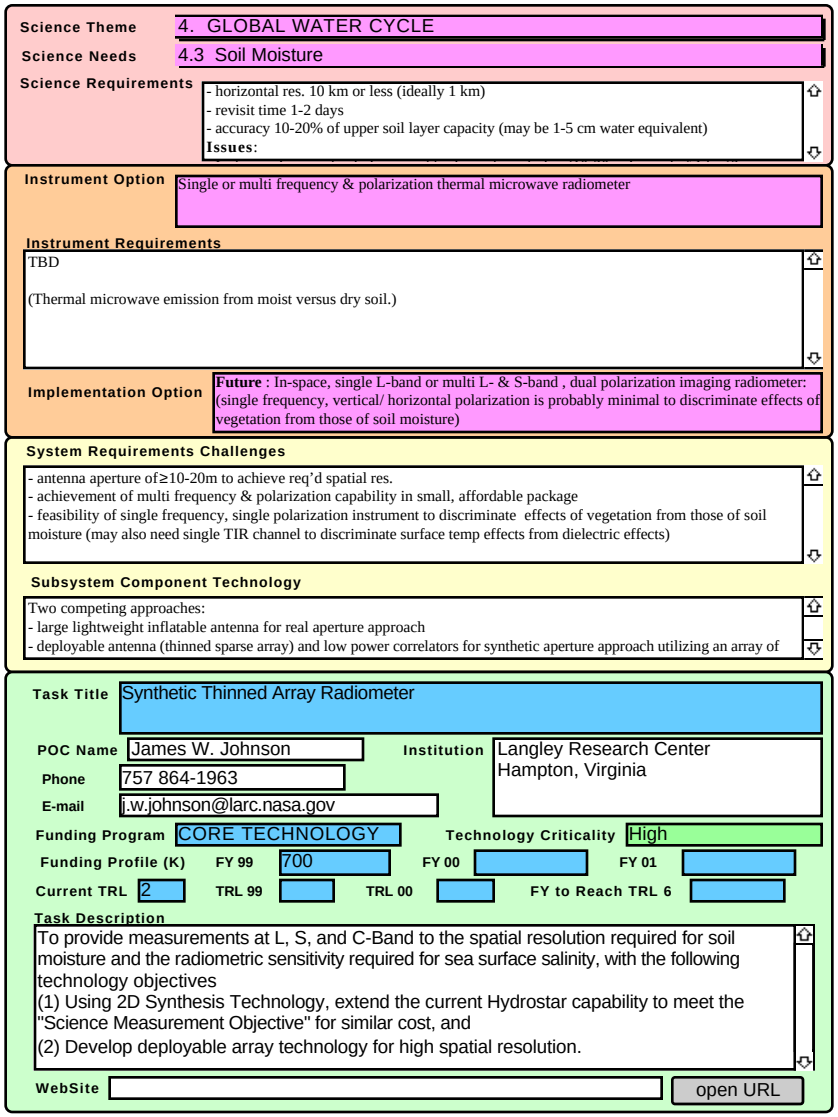
Planning Tool: Sea Surface Salinity Map



Sea Surface Salinity Technology Development

Technology Programs	Technology Projects/Activities		
	Single or Multi-frequency Thermal Microwave Radiometer	**TIR Radiometer**	**Multi-frequency Polarimetric SAR**
CETDP	Frequency selective Bolometer 2.5 THz Planar Mixer Hot Electron Bolometer Receivers High Temperature Superconductor Hot Electron Bolometric Mixer Local Oscillator Multiplexer Local Oscillator Photomixer MMIC Devices Cryogenic HEMT	Coolers & Cryogenics (Advanced Cryocoolers)	Advanced Radar Technology
Core Technology	Synthetic Thinned Array Radiometer		
SBIR	Earth-Orbiting Flight Measurement System (1. Multi-Mega-Pixel CMOS Camera-on-a-chip, 2. Novel and efficient calibration lamps) Microwave Radiometry Technology (1. GaAs Planar Multipliers for Radiometer Applications)	Earth-Orbiting Flight Measurement System (1. Multi-Mega-Pixel CMOS Camera-on-a-chip, 2. Novel and efficient calibration lamps)	SAR for Spacecraft Applications (1. Addressing critical interferometric SAR challenges, 2. Flexible, high bandwidth phased-array antenna)
IIP	Study of a Spaceborne Microwave Instrument for High Resolution Remote Sensing of the Earth Surface Using a Large-Aperture Mesh Antenna		
NMP			
Trade Study	Advanced Microwave Radiometry and Scatterometry Approaches for Surface Hydrology System Study to Address Technology Requirements for Advanced Microwave Radiometry Applications	Thermal Infrared Remote Sensing Focal Plane Technologies for Imaging Spectrometer	High Data-Rate Communication Downlink Trades Employing Phased Array Antennas Use of COTS for Real-Time Processing of SAR Systems Comparison of Remote Sensing Techniques for Measuring Carbon Sequestration
HPCC			

Planning Tool: Sea Surface Salinity



Science Theme 4. GLOBAL WATER CYCLE

Science Needs 4.3 Soil Moisture

Science Requirements

- horizontal res. 10 km or less (ideally 1 km)
- revisit time 1-2 days
- accuracy 10-20% of upper soil layer capacity (may be 1-5 cm water equivalent)

Issues:

Instrument Option Single or multi frequency & polarization thermal microwave radiometer

Instrument Requirements

TBD

(Thermal microwave emission from moist versus dry soil.)

Implementation Option **Future** : In-space, single L-band or multi L- & S-band , dual polarization imaging radiometer: (single frequency, vertical/ horizontal polarization is probably minimal to discriminate effects of vegetation from those of soil moisture)

System Requirements Challenges

- antenna aperture of≥10-20m to achieve req'd spatial res.
- achievement of multi frequency & polarization capability in small, affordable package
- feasibility of single frequency, single polarization instrument to discriminate effects of vegetation from those of soil moisture (may also need single TIR channel to discriminate surface temp effects from dielectric effects)

Subsystem Component Technology

Two competing approaches:
- large lightweight inflatable antenna for real aperture approach
- deployable antenna (thinned sparse array) and low power correlators for synthetic aperture approach utilizing an array of

Task Title Synthetic Thinned Array Radiometer

POC Name James W. Johnson

Institution Langley Research Center
Hampton, Virginia

Phone 757 864-1963

E-mail j.w.johnson@larc.nasa.gov

Funding Program CORE TECHNOLOGY

Technology Criticality High

Funding Profile (K) FY 99 700 FY 00 FY 01

Current TRL 2 TRL 99 TRL 00 FY to Reach TRL 6

Task Description

To provide measurements at L, S, and C-Band to the spatial resolution required for soil moisture and the radiometric sensitivity required for sea surface salinity, with the following technology objectives
(1) Using 2D Synthesis Technology, extend the current Hydrostar capability to meet the "Science Measurement Objective" for similar cost, and
(2) Develop deployable array technology for high spatial resolution.

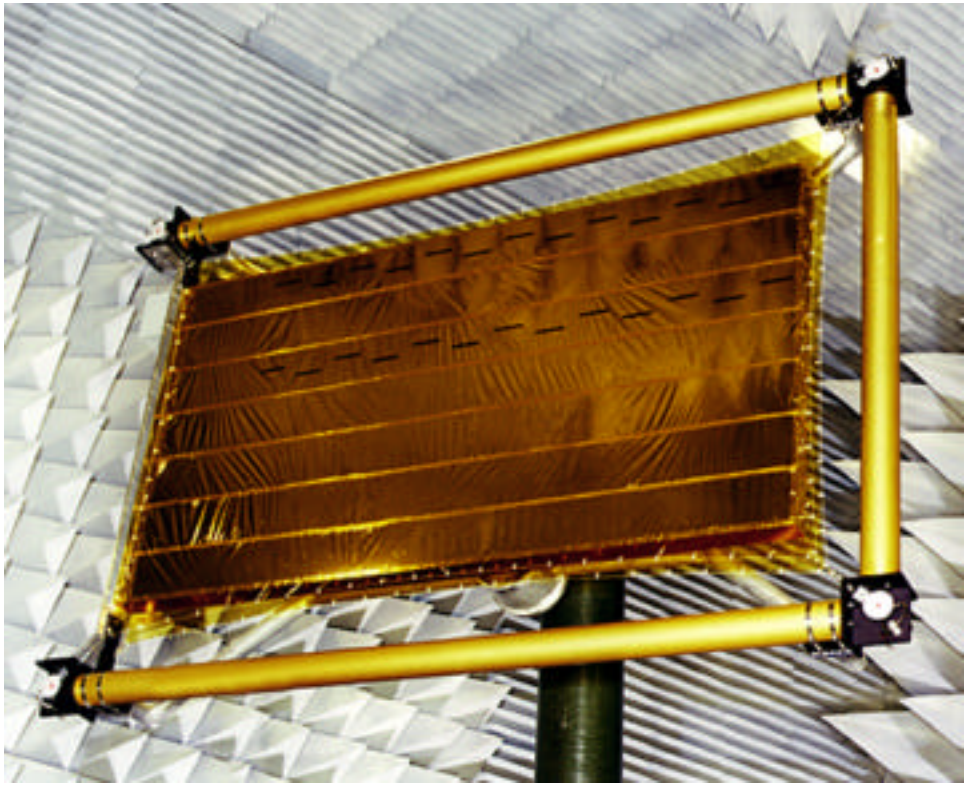
WebSite open URL

Synthetic Thinned Array Radiometry (STAR) for Soil Moisture/Sea Surface Salinity

Technology Objectives:

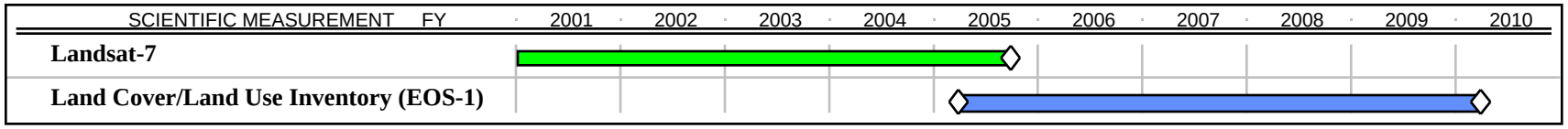
(1) Using 2D Synthesis Technology, extend the current Hydrostar capability to meet the science measurement objectives for similar cost.

(2) 1D Deployable Array Technology for High Spatial Resolution.



Hydrostar	STAR Technology Objectives
L-Band	L, S, and C-Band
H Polarization	H, V Polarization
30 km Resolution	10 km Resolution
1 K Sensitivity	.05 K Sensitivity (@ 100 km)

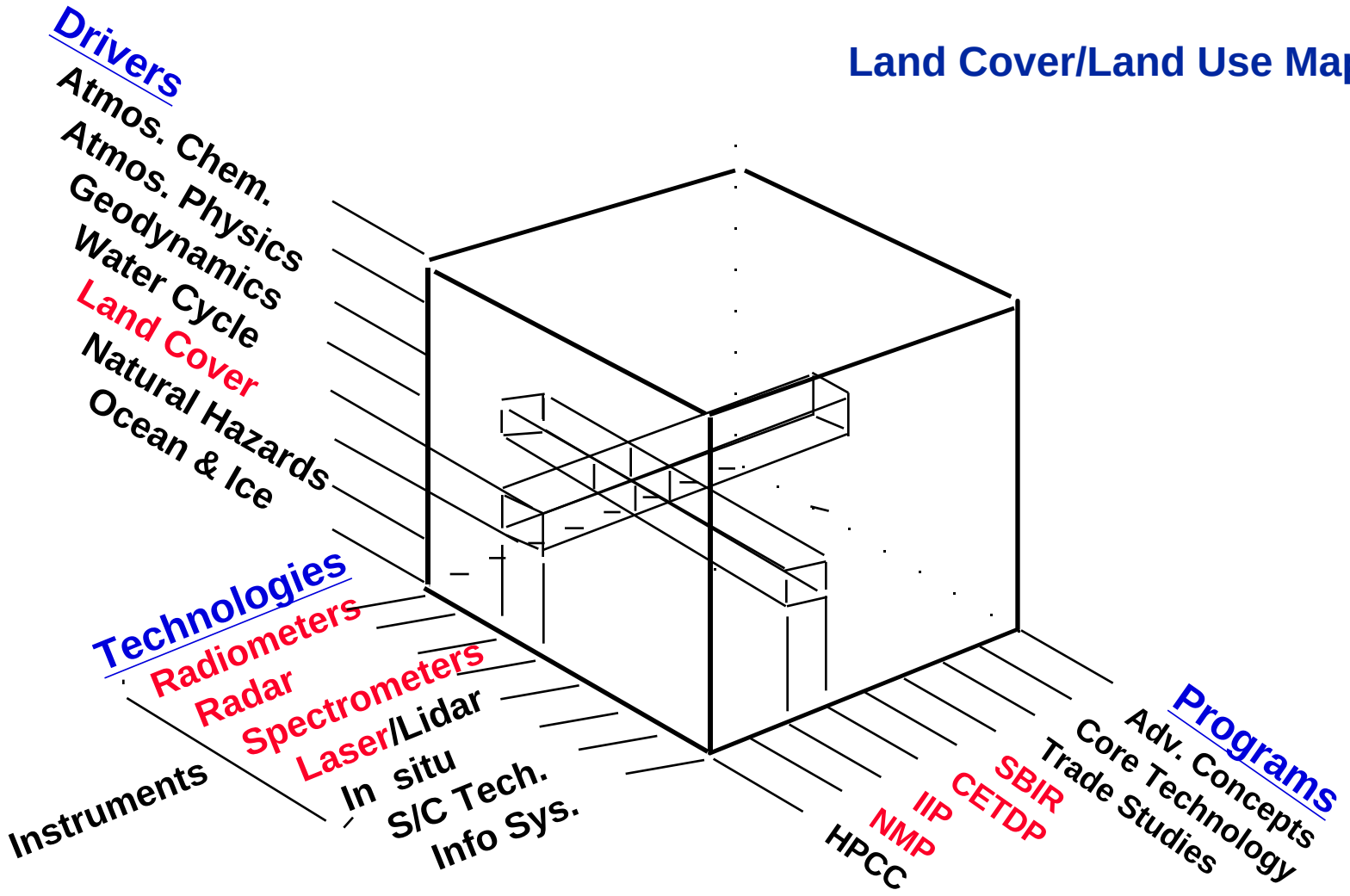
Needs Matrix: Land Cover Example



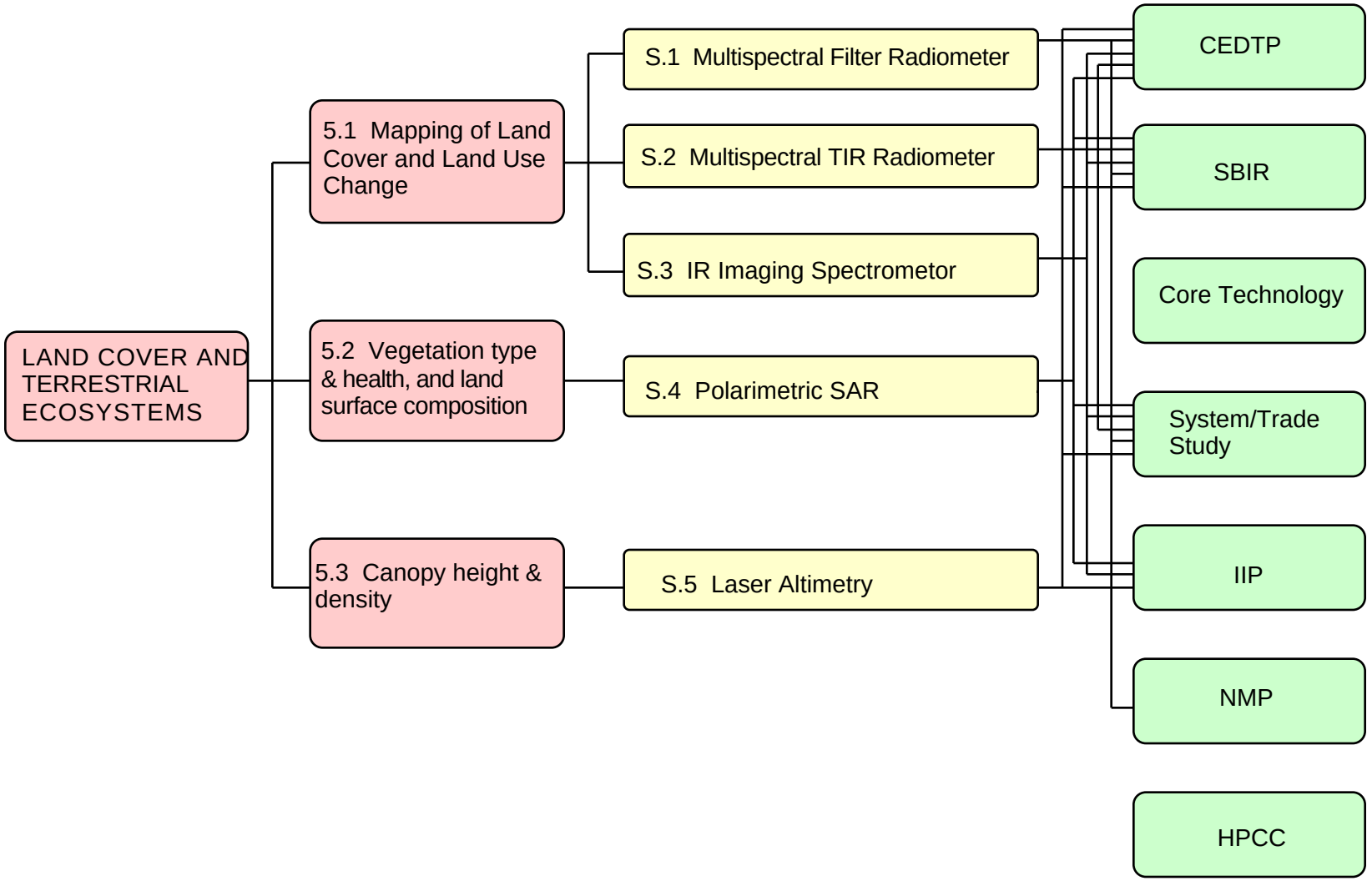
- **Mod. Spatial Resolution Mapping of Land Cover/ Land Use**
  - global coverage
  - horizontal res. 0.5-1 km
  - revisit time 1-2 days
- **Physical Measurement:**
  - Multi-spectral reflectance of the surface under solar illumination
  - Spectral resolution - multi-channel (0.45-2.3µm) and SWIR
- **Current:** Space-based VNIR multi-spectral filter radiometer
- **Future**: MODIS follow-on; Advanced GOES or NPOESS imager
- **Challenges**:
  - Instrument miniaturization
  - Avoiding variable view angles
- **System Requirements:**
  - Compact WFOV optical design
  - Lightweight compact gimbal systems for instrument pointing
  - Accurate and stable onboard calibration
  - Hyper-spectral atmospheric correction
  - Onboard data storage, processing and reduction

Science, Technology and Program Cross-Link

Land Cover/Land Use Mapping



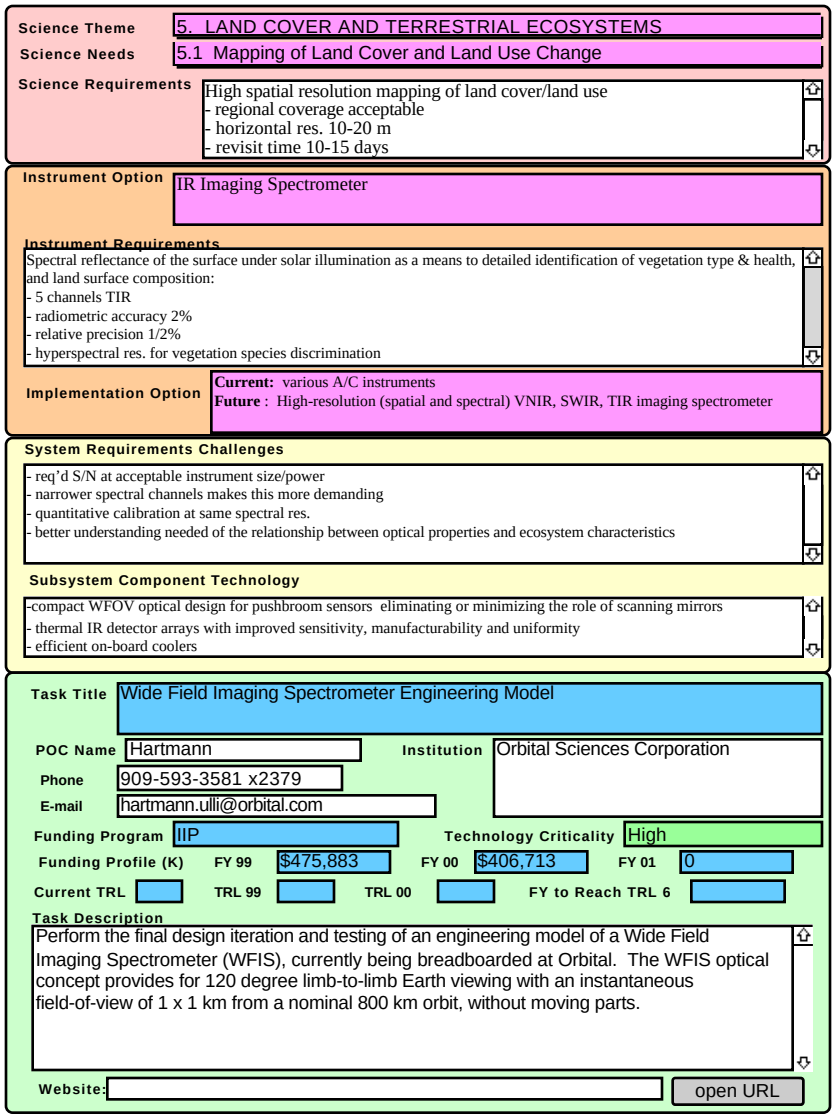
Planning Tool - Land Cover/Land Use Map



Land Cover/ Land Use Change Tech. Development

Technology Programs	Technology Projects/Activities				
	Multispectral Filter Radiometer	**Multispectral TIR Radiometer**	**IR Imaging Spectrometer**	**Polarimetric SAR**	**Laser Altimetry**
CETDP	· STJ Optical Detectors · Wide FOV Spectrometer · Hyperspectral Imager · Surface Plasmon Tunable Filter (SPTF) and Spectrometer-on-a-chip	· Coolers & Cryogenics (Advanced Cryocoolers)	· Coolers & Cryogenics (Advanced Cryocoolers)	· Advanced Radar Technology	· Local Oscillator Photomixer · Laser Transmitter · Advanced Semiconductor Lasers & Photonic ICs
Core Technology SBIR	· Earth-Orbiting Flight Measurement System (1. Multi-Mega-Pixel CMOS Camera-on-a-chip, 2. Novel and efficient calibration lamps)	· Stratospheric and Ecosystem Science Instruments (1. Quantum Cascade Based Field Flux Sensor, 2. Ultrahigh dynamic range, high speed A/D converter for Laser ranging and remote monitoring)	· Remote Sensing Technology for Coastal Research (1. Spectral Image Fusion (SIF) and registration system for hyperspectral and thermal data cubes) · Earth-Orbiting Flight Measurement System (1. Multi-Mega-Pixel CMOS Camera-on-a-chip, 2. Novel and efficient calibration lamps)	· SAR for Spacecraft Applications (1. Addressing critical interferometric SAR challenges, 2. Flexible, high bandwidth phased-array antenna)	· Lidar Systems for Ranging & Altimetry (1. Compact, Solid-State, Q-switched Laser Design, 2. Mid-infrared avalanche photodiode arrays) · Stratospheric and Ecosystem Science Instruments (1. Quantum Cascade Based Field Flux Sensor, 2. Ultrahigh dynamic range, high speed A/D converter for Laser ranging and remote monitoring)
IIP			· Wide Field Imaging Spectrometer Engineering Model	· Two-dimensional Synthetic Aperture Radiometer for Microwave Remote Sensing from Space	· Development of a Hybrid RF/Laser Radar · Multi KiloHZ Micro Laser Altimeters for Earth Science Applications
NMP	· Advanced Land Imager · Compact Telescope · Atmospheric Correlator				

Planning Tool: Land Cover/Land Use



Science Theme: 5. LAND COVER AND TERRESTRIAL ECOSYSTEMS

Science Needs: 5.1 Mapping of Land Cover and Land Use Change

Science Requirements:
High spatial resolution mapping of land cover/land use
- regional coverage acceptable
- horizontal res. 10-20 m
- revisit time 10-15 days

Instrument Option: IR Imaging Spectrometer

Instrument Requirements:
Spectral reflectance of the surface under solar illumination as a means to detailed identification of vegetation type & health, and land surface composition:
- 5 channels TIR
- radiometric accuracy 2%
- relative precision 1/2%
- hyperspectral res. for vegetation species discrimination

Implementation Option:
Current: various A/C instruments
Future : High-resolution (spatial and spectral) VNIR, SWIR, TIR imaging spectrometer

System Requirements Challenges:
- req'd S/N at acceptable instrument size/power
- narrower spectral channels makes this more demanding
- quantitative calibration at same spectral res.
- better understanding needed of the relationship between optical properties and ecosystem characteristics

Subsystem Component Technology:
-compact WFOV optical design for pushbroom sensors eliminating or minimizing the role of scanning mirrors
- thermal IR detector arrays with improved sensitivity, manufacturability and uniformity
- efficient on-board coolers

Task Title: Wide Field Imaging Spectrometer Engineering Model

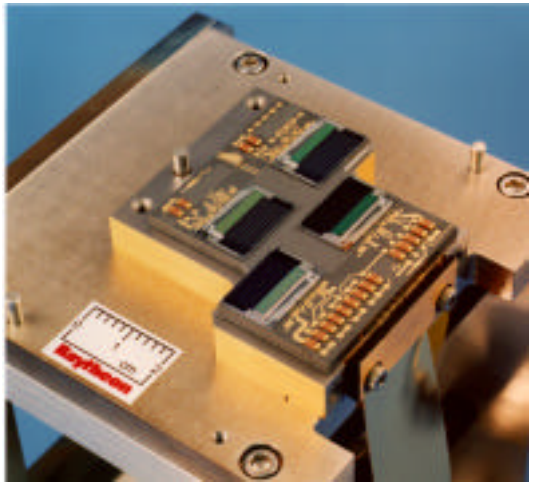
POC Name: Hartmann
Institution: Orbital Sciences Corporation
Phone: 909-593-3581 x2379
E-mail: hartmann.ulli@orbital.com

Funding Program: IIP
Technology Criticality: High
Funding Profile (K): FY 99 $475,883 FY 00 $406,713 FY 01 0
Current TRL: TRL 99 TRL 00 FY to Reach TRL 6

Task Description:
Perform the final design iteration and testing of an engineering model of a Wide Field Imaging Spectrometer (WFIS), currently being breadboarded at Orbital. The WFIS optical concept provides for 120 degree limb-to-limb Earth viewing with an instantaneous field-of-view of 1 x 1 km from a nominal 800 km orbit, without moving parts.

Website: open URL

Land Cover/Land Use Example: EO1 Multispectral Imaging



- *10 bands VNIR/SWIR*
- *0.4-2.5 um spectral region, 30m GSD*
- *Highly integrated sensor chip assembly*

- **Development Status**
  - **Environmental testing completed successfully**
  - **Calibration in full swing and going very smoothly, slightly ahead of schedule, MTF measures in progress**
  - **LL updating ALI thermal model based on results of TV/TB testing.**
  - **Validation Plan Status**
  - **NRA draft at HQ, still under review**
- **Budgetary Status**
  - **Integral part of ALI budget**
- **Issues**
  - **None**
- **Delivery Schedule**
  - **ALI scheduled for delivery on 1/22/99, may be delayed until Feb 8th to allow 1773 changeout.**

Data Info System Cross-link

Science Needs	Instrument Option	CETDP	SBIR	Core Technology	IIP	NMP	Trade Study	HPCC
		TS: 26 of 35 products; SS: 5 of 29 products (in-situ); HRDD: 25 of 25 products	5, 6	1		EO-1	J4, J5, J6	XX

Information-Adaptive Image Classification and Coding for High Data Volume (HSI) Applications

Science Objective:

To develop an information-adaptive processor code that accurately and efficiently classifies and codes HS and FTS image data. This objective encompasses the real-time ***acquisition*** of these data from remote sensors and the near real-time ***dissemination*** of these data.

Technology Objectives:

(1) Wavelet coding algorithm with vector quantization for data classification and (lossless and lossy) compression.

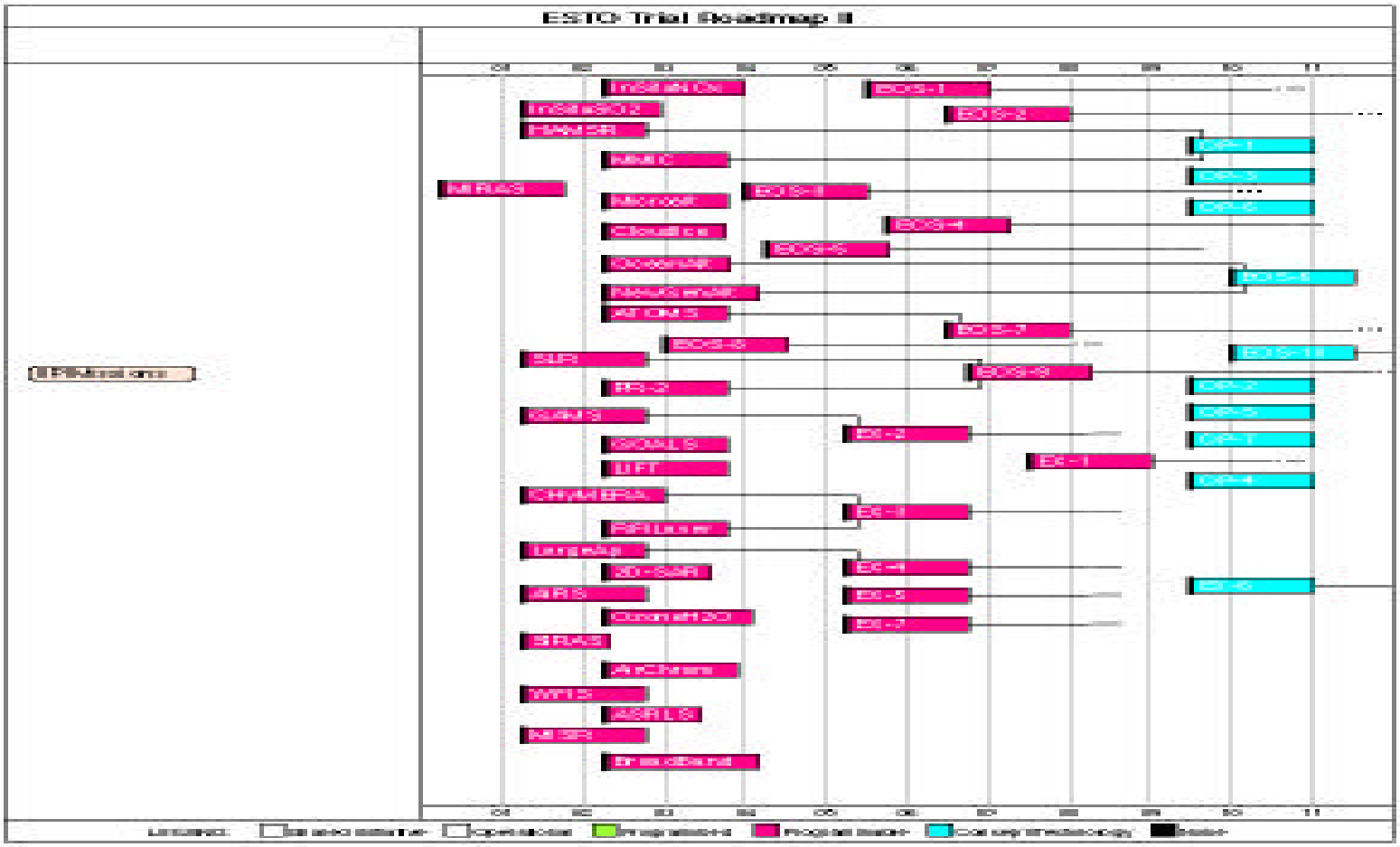
(2) Wiener-matrix filter algorithms for
- the minimum mean-square error presentation of spectral reflectance or absorption cubes, and
- the perceptually sharp and clear display of true and false color images.

(3) Sensor correction (prior to data classification and coding).

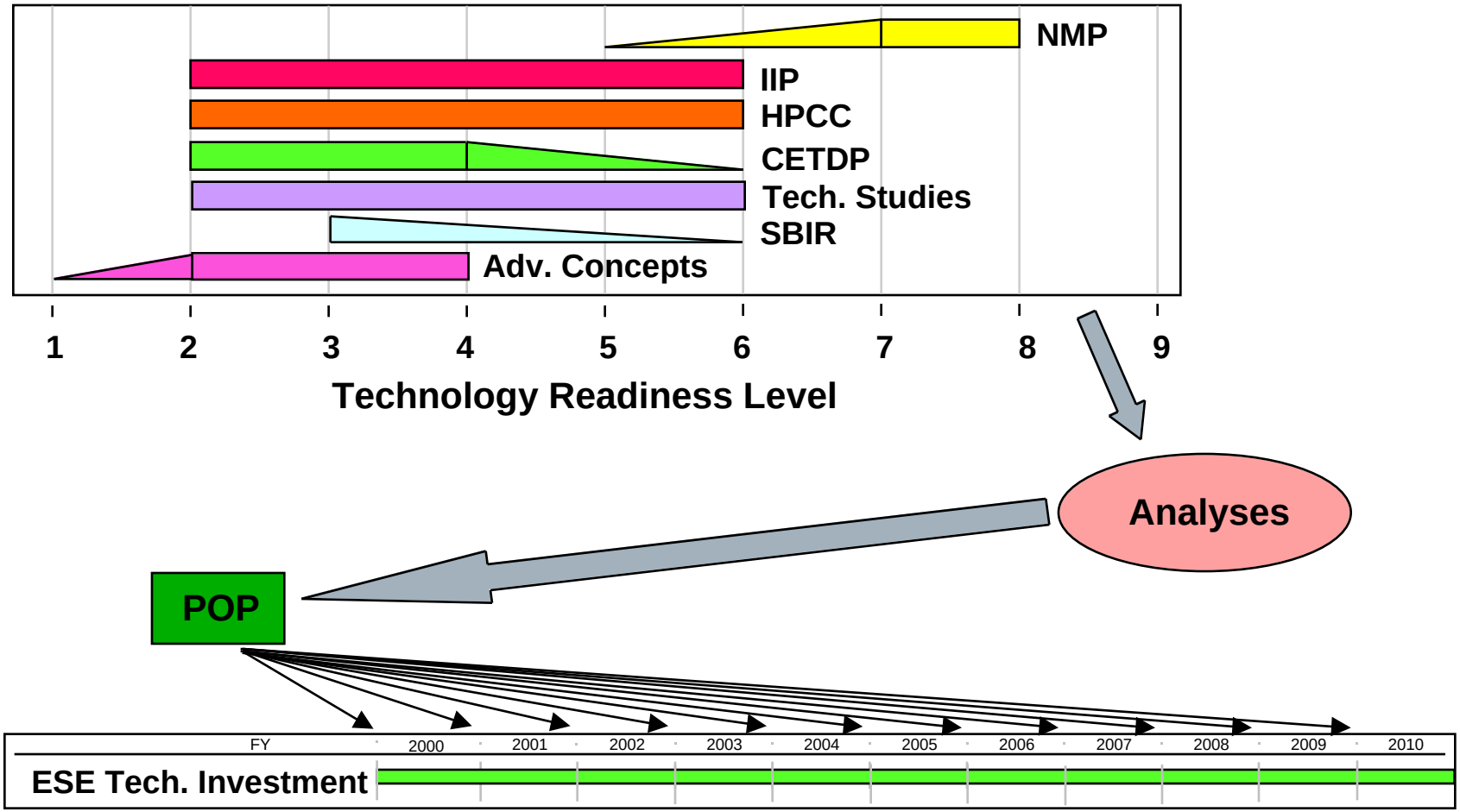
(4) Atmospheric correction for HSI data.

(5) Computational model of the spatial and spectral properties of the atmosphere and surface.

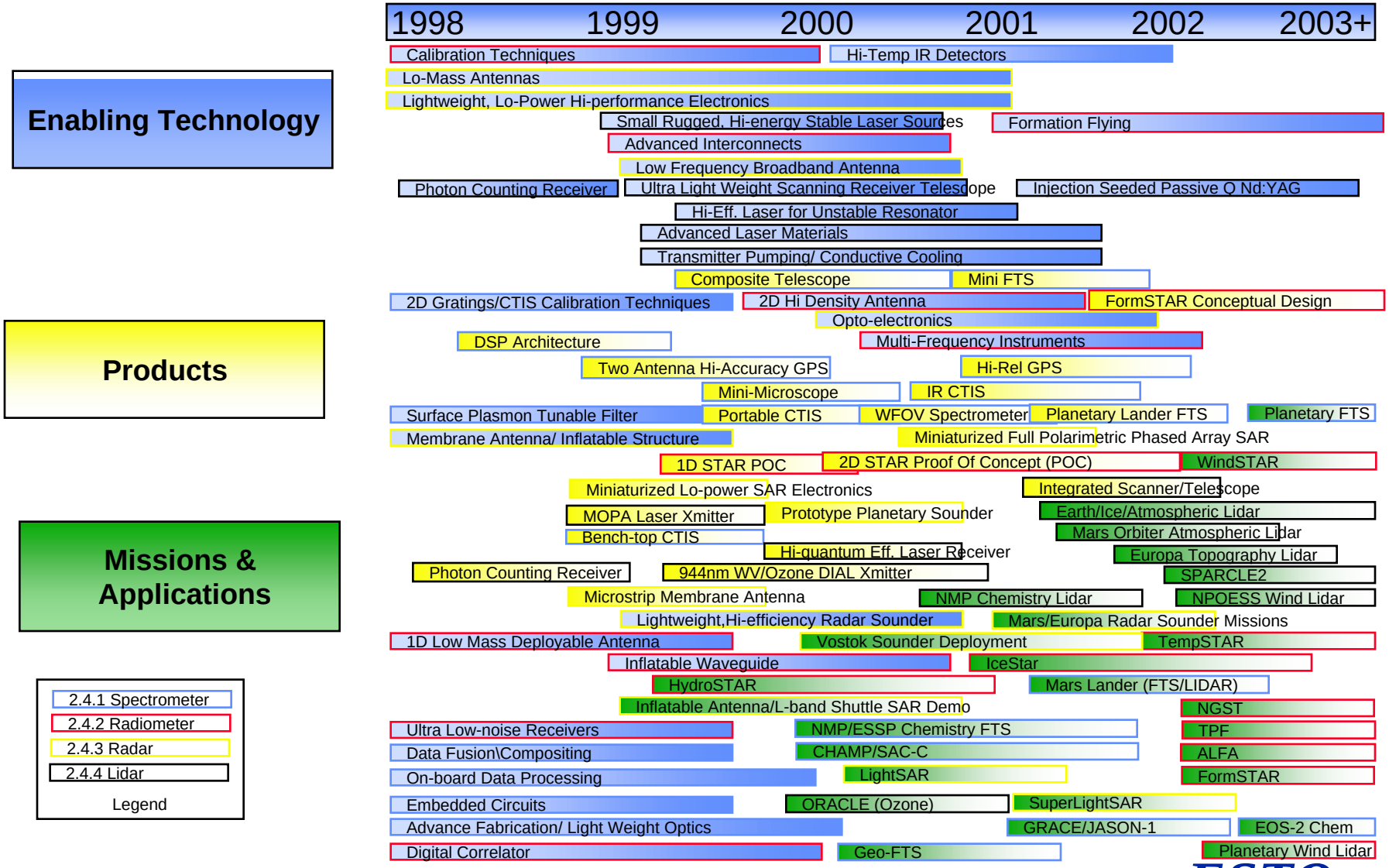
Earth Science Technology Roadmap



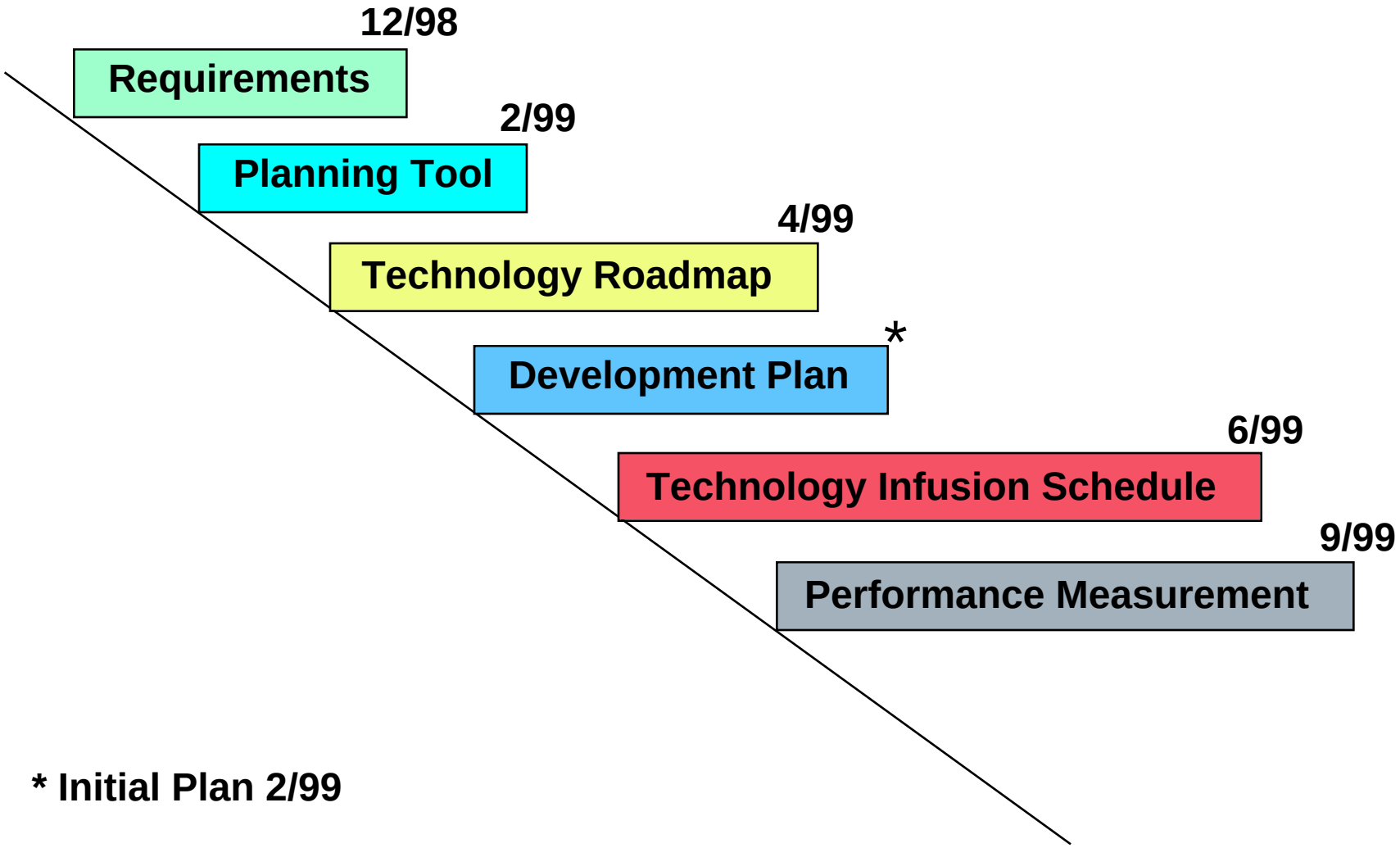
Integrated Technology Development Plan



Integrated Instruments Roadmap



ESTO Near Term Schedule



* Initial Plan 2/99

ESTP Objective

Through development and application of new technology, enable OES programs & missions to effectively and efficiently address Earth system science questions planned in the near-to-mid future and to stimulate new science programs necessary to meet longer term OES goals

ESTP Goals

Maintain a traceable link between science & applications objectives and technology investment

Ensure overall Program cost effectiveness through technology advances and application

Ensure the Program supports 3-year acquisition timelines for flight and ground systems

Ensure the Program considers near, mid and far term horizons

Leverage technology investments through cross-enterprise program synergy and external partnerships

ESTP Performance Metrics

- **Annual approval of the needs database by the OES.**

- At least 50% of near-term technologies have a 2 to 3 years-to-launch horizon

- Annual approval of the Integrated Technology Development Plan by the OES
- Technology funding allocated at 60% for near, 25% for mid, and 15% for far-term research

- At least 25% of development tasks advance by at least one readiness level each year
- Annual transfer of at least one technology development to a commercial entity or into operational use
- Biennial enabling of at least one new science measurement capability enabled via a technology-push development

- Annually establish at least one joint agreement within another NASA program resulting in inclusion of at least 2 ESE requirements
- Annually establish at least one joint agreement with a program external to NASA resulting in inclusion of at least 1 ESE requirement

Organizational Relationships